significantly, cost-effectiveness should be estimated on a case-by-case basis. However, the Port of Long Beach completed its year-long feasibility study in early 2004 on electric power for ships at berth and found shoreside power to be cost-effective for many applications including cruise and container ships.[11]

EXAMPLES ▶ The Swedish port of Göteborg has led the way on commercial shoreside power installations. The Göteborg project alone has reduced 80 tons of NO_x, 60 tons of SO_x, and 2 tons of PM emissions annually because of shoreside power used by ferries and several cargo vessels.[12] Efforts are currently under way to replace fossil-fuel-based shoreside energy with nearby wind energy. Other Northern European ports, such as Lubeck, Germany, have plans for similar electric ship-to-shore projects.

The Princess Tours cruise line followed suit in 2001, installing shoreside power at its terminal in Juneau, Alaska, after incurring several fines averaging $27,500 each for visible smoke from its cruise ships.[13] Although some minor technical difficulties arose during the design and construction phases of the project, they proved surmountable. In fact, Princess reports that the project is working well and that it is pleased with the program overall.[14] Each ship takes 30 to 45 minutes to hook up to the electrical power while docking, requiring an average of 6 to 10 megawatts to run full cruise ship electrical service.

Shoreside power could achieve enormous emission reductions from large oceangoing vessels, which are difficult to regulate because most are operated under foreign flags.

California ports are also slowly catching up. The Port of Oakland installed power plug-ins on a new tugboat wharf in 2001 so that tugboats could shut down their engines while at berth.[15] Oakland considers this too expensive for larger oceangoing vessels; however, the ports of Los Angeles and Long Beach are both actively exploring the possibility. The City of Los Angeles signed a memorandum of understanding with six shipping lines to participate in the development of its alternative marine power (AMP) program, and the port has recently completed electrification of a berth at the China Shipping terminal (see "China Shipping Plugs In," page 24).

Some ports are beginning to use shoreside power for dredging equipment. Electric dredges have been used in various projects in Texas and California.[16]

DISCUSSION ▶ Cold ironing has been practiced in the past and apparently continues to be used by the U.S. Navy. It could achieve enormous emission reductions from large oceangoing vessels, which are difficult to regulate because most are operated under foreign flags. Terminal workers, especially those aboard ships on nearby docks, gain improved working conditions because they are no longer subjected to the exhaust and noise of the auxiliary engines. Of course, shoreside power is also an opportunity to develop such alternative and petroleum-independent power sources as fuel cells.

The viability of cold ironing applications and their ability to power vessels at dock depends greatly on the infrastructure outlay. A surplus of available power on the order of 2 to 10 megawatts is necessary, and land for substation development and cable-laying right-of-way must be available close to the terminals.

In addition, some ships may not have the correct electrical hookups to allow the proper connection. This problem can be overcome, however, by making agreements

CHINA SHIPPING PLUGS IN

The Port of Los Angeles unveiled the world's first electrified container terminal in June 2004, where ships can plug in to shoreside power while at berth instead of continuously running their dirty diesel engines to generate electricity. The new China Shipping Line terminal facility is expected to eliminate at least 1 ton per day of nitrogen oxides and particulate matter for each ship that plugs in, and can accommodate two ships at one time, according to the Port of Los Angeles. The Port of Los Angeles also reports that one vessel call is equivalent to about 69,000 diesel truck miles—enough to drive around the world nearly three times.

The shoreside power facility is part of a legal settlement negotiated by NRDC, Coalition for Clean Air, Communities for a Better Environment, and two San Pedro homeowner groups, who sued the Port and City of Los Angeles in 2001 alleging they had approved the China Shipping Line terminal without considering or mitigating harm to neighboring communities. The final settlement also requires the port to use terminal tractors that run on cleaner, alternative fuels instead of diesel; to evaluate the feasibility of cleaner marine fuels; and to minimize aesthetic impacts of cranes. The port must also establish a $50 million fund for mitigation of air quality and aesthetic impacts in the community, including $10 million to clean up old trucks.

Sources: Port of Los Angeles, Alternative Marine Power, 21 June 2004, http://www.portoflosangeles.org/Environmental/AMP.htm (29 June 2004).

or memoranda of understanding with shipping lines and terminal operators during lease agreements or renewals.

The Port of Los Angeles reports that pollution from one vessel call is equivalent to about 69,000 diesel truck miles—enough to drive around the world nearly three times.

Cleaner Fuels

Ports should significantly reduce emissions from marine vessels by requiring reduced sulfur content of marine diesel fuel. Large oceangoing marine vessels are notorious for running on bunker fuel, the dirtiest grade of diesel. We recommend that ships run on fuel with the lowest sulfur content possible, from 15 to 2,000 ppm.

Higher sulfur content fuels cause increased emissions of NO_x, SO_x, and PMs. Although cleaner running vessels are slowly penetrating the U.S. market (see "Quiet, Clean, Hybrid Marine Power," page 33), current marine diesel fuel can reach levels as high as 50,000 ppm sulfur (5 percent by weight). These high sulfur levels are approximately 15 times as great as current EPA non-road diesel fuel standards and 100 times as great as current EPA on-road fuel standards. Several lower-sulfur and alternative fuel options are available that are compatible with existing oceangoing and harbor-craft marine vessel engines, including fuels currently used for nonroad and on-road vehicular applications.

According to the International Organization for Standardization (ISO 8217), 19 categories of marine residual fuels are available internationally. The lowest sulfur content fuel grade must have sulfur content less than 1 percent sulfur (10,000 ppm). Table 2-3 summarizes the most common of these marine fuel specifications under ISO 8217.

The widely accepted average for marine bunker fuels in use by ships around the globe is approximately 2.7 percent sulfur (27,000 ppm). For comparison purposes,

Table 2-4 lists the various national and international sulfur content fuels that are either in use today or slated for use in the near future. Because these fuels are available nationally, and because global conventions have recognized the need for lower sulfur content fuels (see Appendix D for more information on international rules governing marine fuels), several cleaner-fuel options are available for marine propulsion and auxiliary engines, as well as for on-board, backup generators. In addition, the use of cleaner, lower-sulfur fuels enables the use of a wider range of control technologies on these engines.

Some marine vessels will be required by the EPA under its recent nonroad rule to use a cleaner blend of diesel (500 ppm sulfur) starting in 2007, and an even cleaner blend (15 ppm sulfur) starting in 2012.[17] (See Chapter 3 for details.)

TABLE 2-3
Summary of Marine Fuel Specifications

Marine Fuel Specification	Maximum Sulfur Content
Heavy fuel oil (HFO)—includes IFO380 and IFO180 (also known as bunker fuel, or BFO)	5% or 50,000 ppm
Marine Diesel Oil (MDO)—DMC	2% or 20,000 ppm
Marine Diesel Oil (MDO)—DMB (slightly lower density and viscosity than DMC)	2% or 20,000 ppm
Marine Gas Oil (MGO)—DMA	1.5% or 15,000 ppm
Marine Gas Oil (MGO)—DMX	1% or 10,000 ppm

Source: Marine fuel specifications according to the International Organization for Standardization (ISO 8217:1996) available at www.bunkerworld.com/technical/iso8217_res.htm.

Note: Marine diesel oil and marine gas oil are considered distillates and marine diesel oil is a blend of gas oil and heavy oil. Wihin each fuel grade category, the sulfur content of available fuels for purchase can be significantly lower than the maximum allowable sulfur content specified in the table.

TABLE 2-4
Summary of Sulfur Content in Various Fuels

SULFUR CONTENT		
percent	**ppm**	**Example of Current Usage or Status**
4.5	45,000	Maximum allowable level for marine fuels in the International Convention for the Prevention of Pollution From Ships (MARPOL)
2.7	27,000	Average for marine fuels (widely accepted global average)
1.5	15,000	Recently proposed by EU as its cap for marine vessels in the North Sea, English Channel, and Baltic Sea
0.5	5,000	Current U.S. EPA nonroad diesel fuel standard, which does not include marine vessels
0.1	1,000	Recently proposed by EU for marine vessels while berthed in EU ports beginning in 2010
0.05	500	Current U.S. EPA on-road diesel fuel standard
0.015	150	Current California on-road diesel fuel standard
0.0015	15	U.S. EPA on-road and California on-road and off-road diesel planned for mid-2006

Sources: *Draft Regulatory Support Document: Control of Emissions From Compression-Ignition Marine Diesel Engines at or Above 30 Liters per Cylinder*, Office of Transportation and Air Quality, U.S. EPA, April 2002, available at europa.eu.int/comm/environment/air/transport.htm#3; and EU Directive 99/32/EC, available at www.dieselnet.com/standards/fuels/.

Other cleaner-burning fuels that may be used for ferries, harbor craft, and other non-oceangoing vessels include emulsified diesel, biodiesel, compressed natural gas (CNG), or liquefied natural gas (LNG). These are potential options that can result in significant reductions in NO_x and PM emissions.

Prior to regulation, a transition to cleaner marine fuels can be facilitated through the use of incentive programs, including harbor fees or taxes that favor ships using cleaner fuels (see "Sweden Harbor Fees Deter Dirty Ships," page 32). In the absence of mandated emission control areas, incentive programs would have more success if implemented nationally or at least regionally.

Pollutants Reduced The three primary pollutants affected by the use of lower-sulfur fuel are SO_x, NO_x, and PM. Except for SO_x, the emission reduction value of lower-sulfur fuel is highly variable and depends greatly on the make, age, and quality of maintenance on the engine, the duty cycle, and many more factors.

The amount of sulfur in ship emissions is equivalent to the amount of sulfur in the fuel. Therefore, the amount of SO_x that will be reduced with use of the lower-sulfur diesel is a direct function of the level of sulfur reduced. Typically, however, a reduction from standard marine fuel with 2.7 percent sulfur content to a fuel with 0.3 percent sulfur content will yield approximately a 90 percent reduction in SO_x emissions.[18]

The cleaner fuel will affect PM emissions, both directly and indirectly. Because both SO_x and NO_x contribute to PM formation, reductions in these emissions also reduce particulate levels. PM is also reduced directly by the cleaner fuel.

According to the EPA, a switch of all vessel operations within 175 nautical miles of the U.S. coast would result in significant reductions in PM and SO_x emissions.[19] Table 2-5 shows that PM and SO_x can be reduced dramatically by changing to lower-sulfur diesel in marine engines.

NO_x reductions are more difficult to estimate. A reduction of approximately 10 percent may be realized when a ship uses a distillate fuel instead of heavy fuel oil.[20] Further NO_x reductions may be achieved when utilizing CARB on-road diesel due to lower aromatics, but these emission reductions have not been widely demonstrated in practice.[21]

PM and SO_x can be reduced dramatically by changing to lower-sulfur diesel in marine engines.

Unit Cost Whereas the price and quality of bunker fuel vary greatly, distillate fuels typically cost 50 percent more.[22] As with on-road applications, the price paid for marine fuel will fluctuate with the market and the purchase volume.

TABLE 2-5
Pollutants Reduced by Lower Sulfur Content Marine Fuels

Marine Fuel Sulfur Content	PM	SO_x
1.5% (15,000 ppm)	18%	44%
0.3% (3,000 ppm)	63%	89%

Source: Office of Transportation and Air Quality, U.S. EPA, "Draft Regulatory Support Document: Control of Emissions From Compression-Ignition Marine Diesel Engines at or Above 30 Liters per Cylinder," April 2002.

Note: Reductions are as compared to 27,000 ppm or 2.7 percent sulfur content.

SCX, Inc., a ferry manufacturer, successfully completed a demonstration project utilizing 15 ppm sulfur diesel in a ferryboat at the Port of Los Angeles. British Petroleum's ECD-1 fuel was used for the project, and the success encouraged British Petroleum to change its specifications to commit to the IMO marine fuel requirement of a minimum 60-degree Celsius flashpoint and recruit a local distributor to supply the fuel within the port.[23,24] The cost of the ECD-1 fuel will be nearly twice that of bunker fuel.

Cost-Effectiveness Because of the limited implementation of this measure in the United States and because costs are likely to vary significantly, cost-effectiveness cannot be accurately estimated.

EXAMPLES ▶ In addition to the SCX, Inc. demonstration project and many others like it, Samsung Heavy Industries, a major cargo ship manufacturer, has designed one of its newest ships, the Orient Overseas Container Line (OOCL) Long Beach, to operate on lower-sulfur fuel (although it is not doing so at the moment). OOCL plans to acquire a few more ships in this class, capable of carrying more than 8,000 containers, and then operate them at the Port of Long Beach.

Water taxis in Newport, Rhode Island, are running on 100 percent biodiesel, as does a larger boat at Channel Islands National Park.[25] The Port of Helsinki uses lower-sulfur diesel (30 ppm) in several marine vessels. Helsinki has also proposed the use of cleaner fuels in marine vessels for its large new Vousaari Container Terminal Complex.

DISCUSSION ▶ As Table 2-3 indicates, a number of lower sulfur content fuels are on the market. Their availability should alleviate the concerns about supply of lower-sulfur diesel fuel for marine vessels. For example, because of California's current on-road diesel fuel standards, today's diesel users should be able to rely on the availability of 150 parts per million (ppm) sulfur content fuel, and by mid-2006 diesel with 15 ppm sulfur content will be widely available. Furthermore, California's 2003 proposed state implementation plan for air pollution reduction includes provisions that would require the 15 ppm sulfur on-road diesel scheduled for availability in mid-2006 to also be available as marine fuel.[26]

Across the Atlantic, the European Union has made some headway in using lower sulfur content fuels. Before Annex VI of MARPOL was officially ratified, the European Union adopted a directive (E.U. Directive 99/32/EC) to strengthen sulfur limits in marine fuels so that member countries would comply in the meantime. The directive will impose a 1.5 percent (15,000 ppm) sulfur limit on all vessels that travel in the North Sea, the English Channel, and the Baltic Sea. Additionally, it is being strengthened to require all passenger vessels in regular service to or from any port in the European Union to use fuel with a sulfur limit of 1.5 percent. And finally, a 0.2 percent (2,000 ppm) and eventually a 0.1 percent (1,000 ppm) sulfur limit will be imposed on all inland water vessels and all ships while they are berthed in ports inside the European Union. (As we went to press, EU representatives came to political agreement about dropping the first 0.2 percent fuel sulfur requirement, but retaining the 0.1 percent fuel sulfur requirement starting in 2010. For more details, see Appendix D.)

Although the EU directive has not been formally ratified, refiners have already begun to supply 2,000 ppm distillates to the European market. The majority of marine gas oil meets the 2,000 ppm threshold, and half of the supplying countries are providing 2,000 ppm marine diesel oil to some degree. Market surveys performed in the European Union found that sulfur distillates of less than 2,000 ppm are available at approximately 95 to 99 percent of EU ports.[27,28]

Because ships will be required to use 2,000 ppm sulfur fuels only while berthed in an EU port, they can take on the required fuel in the port of call. Thus the in-port requirement will apply to all vessels, regardless of their flag state and regardless of their last port of call. The United States should follow suit by requiring 2,000 ppm or less sulfur content fuel for all oceangoing vessels while berthed at ports nationwide. According to Port of Los Angeles staff, one shipping line is currently testing the use of 2,000 ppm sulfur content fuel while berthed at the port.[29]

Regulatory agencies, vessel operators, fuel providers, and environmental groups are now discussing the technical and safety considerations of using lower sulfur content fuels on large oceangoing vessels. Concerns include the flashpoint, the lubricity, and the ability to switch between multiple fuels on board the vessels.[30] (See Appendix B.) In the area of fuel logistics, ports face some uncertainties with respect to the technical feasibility and constraints on-board ships to store and use two different grades of fuel. Modern ships may not have two separate fuel tanks. Some can use only the lower-sulfur fuel; some must be retrofitted for second fuel grade capabilities. Historically, distillate fuels, not heavy fuel oil, have been used in harbors for maneuvering and start-ups of marine engines. Marine distillate fuels were more reliable and did not require preheating for start-ups.

The United States should follow suit by requiring 2,000 ppm or less sulfur content fuel for all oceangoing vessels while berthed at ports nationwide.

Oceangoing vessels average three engines, with one to two main engines and one to two auxiliary engines per ship.[31] In anticipation of the EU directive, one company has developed an automatic system for switching between fuels. The design protects the integrity and efficiency of fuel pumps and fuel valve injection nozzles from the change in viscosity and also addresses the risk of fuel pumps sticking because of temperature variations.[32]

In addition, because most marine vessels have more than one engine, they should be able to carry and use two grades of fuel. According to an EU report on the subject, "There are still a significant number of vessels built with the capacity to switch to distillates for the purposes of starting engines as well as maneuvering in port."[33]

Cleaner Ships

Although ports cannot require oceangoing ships to meet more stringent emission standards, ports should set up incentives for ships making frequent calls at a port to use emission controls. Incentives should take the form of differentiated harbor fees or direct cash grants to shipping lines.

Oceangoing ship emissions are virtually unregulated because they traverse international boundaries. Moreover, international standards will not come into force until next year, and these standards will be quite weak and will apply only to newer ships.

Therefore, creative local and national incentives or requirements are necessary if ship emissions are to be reduced in coastal areas.

Sweden's differentiated harbor fees are a good example of what can be done by way of incentives (see "Swedish Harbor Fees Deter Dirty Ships," page 32). When ships enter Swedish harbors, discounts are given to those using lower-sulfur fuel or NO_x emission controls. California is evaluating this strategy, along with economic incentives for cleaner ships through the addition of pollution controls or the replacement of engines with cleaner models.[34]

Available Technologies Selective catalytic reduction (SCR) can achieve NO_x reductions of 80 percent or more. Although it was developed for such stationary sources as power plants, it has been successfully adapted to large marine vessels. The evidence indicates, however, that the cost of this technology can be prohibitive and that, in some instances, use of existing marine SCR systems has been discontinued due to cost. Furthermore,

TABLE 2-6
Control Technologies for Marine Vessels

Control Technology	Percent NO_x Reductions	Percent PM Reductions	Cost of Equipment	Cost of Operation and Maintenance	Comments
Selective Catalytic Reduction (SCR)	80–90		$260,000 to $1.23 million ($40–$94 per HP)	$24,000 to $144,000 per year	Available; requires significant space and storage for urea
Direct Water Injection	50–60		$20–$40 per HP	$1–$4 per 1,000 HP	Still under development; possible corrosion problems; may require lower-sulfur fuel
Continuous Water Injection	20–30	Up to 25	~$33,000	~$530/year	Still under development; possible demo; on ferry vessel in British Columbia
Fuel Injection Modifications	5–30	25–50	*Note: Only possible for new engines, therefore cost cannot be determined*		Available; may reduce VOCs and improve fuel economy
Humid Air Motor	40–80	N/A	N/A	N/A	Transitioning from development to market
Combustion Air Saturation Systems (CASS)	70	N/A	N/A	N/A	Under development
Emulsified Fuels	15–50	50-63	Up to $217,000	Up to $36,000	Transitioning from development to market; used in Port of Houston tour boat but discontinued due to power loss; possible increase in VOCs and CO and reduction in power
Diesel Oxidation Catalyst (DOC)	N/A	15-30	$3–$15 per HP	N/A	Available; must use lower-sulfur fuel
Diesel Particulate Filter (DPF)	N/A	70-90	$14–$30 per HP	$150 to $300 per year	Under development for marine use; requires ultra low sulfur diesel

Sources: Draft Oceangoing Marine Vessel Emission Control Technology Matrix, California Air Resources Board, Maritime Working Group, 30 Oct. 2002. Various presentations during 26 July 2002 made to the Maritime Air Quality Technical Working Group and Incentives Subgroup; and CARB.

SCR technology still has several problems to overcome before it can be a fully successful NO_x control strategy for marine diesel engines. Urea, the chemical relied on by SCR to reduce NO_x emissions, can become a problem pollutant itself. Without the use of low-sulfur diesel and additional controls—oxidation catalysts, for example—the problem is worsened. Finally, it is difficult to enforce the actual use, instead of bypass, of these systems because engines operate whether or not an installed SCR system is functioning.

Other promising NO_x reduction technologies are currently under development for marine diesel engines. Direct water injection can reduce NO_x by as much as 60 percent, and humid air motors can reduce NO_x by 40 to 80 percent. Both technologies are based on a similar principle—lowering engine temperatures—and have been tested on a number of ferries running in the Baltic Sea. Several variations on the technology have been developed, such as continuous water injection and combustion air saturation systems, reducing NO_x up to 30 percent and 70 percent, respectively. Some of these technologies have the added benefit of reducing some other pollutants as well. Various engine modifications can achieve additional NO_x reductions of up to 30 percent and PM reductions of up to 50 percent.

Many of the particulate matter controls discussed in the measures for cargo-handling equipment and trucks may also be practical for use on large ships. The California Air Resources Board is funding a U.S. Navy study of one such control, diesel particulate filters on marine military craft. It is also possible to install DOCs on ships; however, both DOCs and DPFs require much lower sulfur levels than current marine-grade fuels.

Oceangoing ship emissions are virtually unregulated because they traverse international boundaries.

Pollutants Reduced and Cost As outlined earlier, pollutants reduced include NO_x and diesel PM, depending on the control technology. Some controls also reduce such other pollutants as VOCs and SO_x. The CARB maritime working group has compiled a matrix of controls and cost data, summarized in Table 2-6.

Cost-Effectiveness Not enough information is available at the time of this report to estimate cost-effectiveness.

EXAMPLES ▶ More than 100 large ships, mostly in the Baltic Sea area, have installed selective catalytic reduction (SCR) to reduce drastically the smog-forming nitrogen oxides (NO_x) coming out of their smokestacks. Several U.S. ships have done the same. In California, for example, four large oceangoing vessels and one dredging vessel use SCR systems.

In addition to the Swedish harbor fee system, Finnish and Norwegian ports have either proposed or implemented similar programs to reduce port fees or taxes for cleaner vessels.

DISCUSSION ▶ In addition to the emission controls outlined earlier, many other steps can be taken to reduce visible emissions or smoke and other pollutants through maintenance, operational controls, and local ordinances. Smoke from ship stacks can be controlled and reduced through the following engine maintenance efforts:[35]

- Regular cleaning of the engine turbo charging system
- Regular cleaning of the fuel injection system
- Maintenance to limit lube oil consumption in piston rings and cylinder liners
- Limiting the amount of used lube oil in marine fuels
- Regular cleaning and maintenance of the automated fuel viscosity control system
- Limiting fuel consumption during acceleration mode in cold climates
- Limiting heat removal from the waste heat boilers

Operational behavior can also be changed to reduce emissions, especially in coastal areas. For example, ships often "blow" their stacks to remove soot buildup within the stacks to run more efficiently and prevent fires. But to prevent the release of excess soot emissions, ships should avoid blowing their stacks near shore. Many port areas have instituted "smoking ship" programs to enforce this. Other operational control measures, such as voluntary speed reductions, can also reduce NO_x emissions. However, speed reductions are difficult to enforce and can lead to increased emissions in other areas if ships attempt to make up lost time.

The state of Alaska requires cruise ships within three miles of the coastline to keep their visible emissions below a threshold of 20 percent opacity. Other areas, such as Southern California and Savannah, Georgia, have less stringent smoking

SWEDISH HARBOR FEES DETER DIRTY SHIPS

In 1996, the Swedish Maritime Administration, the Swedish Shipowners' Association, and the Swedish ports made an agreement to implement stringent pollution reduction measures, which aimed to reduce emissions by 75 percent by the year 2000. In an attempt to achieve this goal, the organizations decided to provide economic incentives in the way of differentiated fairway and port dues. Ships that used lower-sulfur bunker fuel and controls to decrease NO_x emissions would pay smaller shipping costs.

For example, an oil tanker carrying a cargo of mineral oil products in bulk, that has attained an emission level of a maximum 2 grams per kilowatt-hour (g/kWh) is charged the minimum amount. Following a linear scale, with an increasing rate of 6 percent per g/kWh, the amount for an emission level exceeding 12 g/kWh will increase by 60 percent. For other vessel types, the amounts increase at a rate of about 7 percent per g/kWh.

Additionally, to promote the installation of emission controls, the Swedish Maritime Administration reimburses the fairway dues that are paid for a five-year period. The cost of installations, that qualify for the reimbursement can be as high as 40 percent of the investment cost if emission controls are installed before the year 2000, and up to 30 percent for installations thereafter. Finally, ships are given an additional rebate per unit of the ship's gross tonnage if the sulfur content of the bunker fuel is lower than 0.5 percent (5,000 parts per million) for passenger ships and 1 percent (10,000 parts per million) for other ships. Following Sweden's lead, Finnish and Norwegian ports have proposed or implemented similar programs, reducing port fees or taxes for cleaner vessels.

Source: www.sjofartsverket.se/tabla-b-eng/pdf/b142.pdf.

ship programs. Southern California also has a speed-reduction program, as detailed in Chapter 3.

CARGO-HANDLING EQUIPMENT

Ports should pursue three major cleanup strategies for cargo-handling equipment, depending on the age of the equipment. First, equipment more than ten years old should be replaced with either alternative-fuel engines that run on propane or natural gas, or with battery-electric hybrid systems. Second, existing equipment less than ten years old should be repowered or retrofitted with the best available control technology, such as diesel particulate filters (DPFs) with lean NO_x catalysts (LNCs) where possible, and diesel oxidation catalysts (DOCs) where DPFs are not practical. Third,

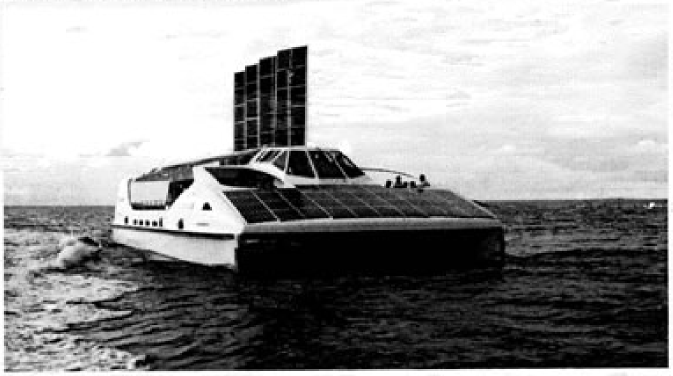
QUIET, CLEAN, HYBRID MARINE POWER

Just as Honda and Toyota are leading the automotive industry in the transition to hybrid passenger vehicles, an Australian-based company called Solar Sailor is working to take the lead for marine vessel applications. By creating electricity from solar power, using available wind energy, and combining this with backup power from modern batteries and fossil fuel generators, Solar Sailor has produced vessels with zero water pollution, low noise, and minimal emissions.

These boats, which have a proven track record in Australia, are ideal for low-speed applications, less than 25 knots, and can be used in tourism, patrolling land, recreational, and transport markets.

In addition, Solar Sailor can retrofit boats running on fossil fuels to function on hybrid marine power. Solar Sailor can customize a retrofit to suit nearly all marine applications where constant high-speed operations are not required. For higher speeds, a generator can be used to power the electric drive directly. The vessels constructed and retrofitted by Solar Sailor can hold up to 250 passengers and produce up to 1,000 horsepower. These hybrid vessels will serve as an immediate platform for the use of fuel cells when they become commercially available.

Source: www.solarsailor.com.au/aboutus.htm.



WWW.SOLARSAILOR.COM

existing equipment should be switched to cleaner diesel fuels, such as low-sulfur fuel with DPFs or diesel emulsions with DOCs.

Purchase New Equipment That Uses Alternative Fuels

Ports should replace older diesel-powered cargo-handling equipment at container terminals with equipment powered by alternative fuel, where possible. Specifically, natural gas, propane, or battery-electric systems would be required for all new purchases.[36] Where possible, ports should also adopt policies that require the purchase of new alternative-fuel cargo-handling equipment as a condition of all new leases and significant lease renegotiations.[37] Diesel equipment that is ten years old or older should be targeted for replacement. These recommendations might necessitate the installation of fueling stations for alternative fuels throughout port terminals.

Certified natural gas engines are available and are used widely in transit bus fleets operating throughout the country. In fact, the same manufacturers that make natural gas bus engines produce conventional diesel engines for cargo-handling equipment.[38]

The vehicles and equipment in this category are powered by off-road engines, ranging from 100 to 500 horsepower (HP), depending on the application. Equipment with known alternative-fuel, electric, or electric hybrid models available are outlined in Table 2-7. The four types of yard equipment in this table—terminal tractors, straddle carriers, rubber-tired gantry cranes (RTGs), and forklifts—make up the majority of cargo-handling equipment and also account for the majority of pollution from equipment at ports.[39] It should be noted that other pre-1996 cargo-handling equipment, for which alternative-fuel, electric, or hybrid-electric options are not available, should still be retired and replaced with cleaner new models. Where possible, those new diesel models should incorporate cleaner on-road, instead of nonroad, engines. Also, where possible, vehicles and equipment that predate standards but are not quite ten years old (for example, eight years old or pre-1996), should be slated for replacement.

Much of the cargo-handling equipment at the Port of Los Angeles runs on diesel emulsions, a cleaner diesel fuel, with simple emission controls that reduce pollution.

TOM PLENYS

Pollutants Reduced Replacing older equipment with equipment powered by alternative fuels significantly reduces emissions of toxic diesel PM, NO_x, and other pollutants. The South Coast Air Quality Management District recently reported that, compared with conventional diesel technology, natural gas technology can reduce more than 60 percent more NO_x and 30 percent more PM in terminal tractors.[40] Although natural gas engines have significantly lower NO_x and PM emissions, they will likely have slightly higher CO and VOC emissions. However, the increase in CO and VOC emissions is small compared with the decrease in NO_x and PM emissions.[41]

Table 2-8 shows the total pollutant reductions obtained in three Southern California demonstration projects where non-road diesel vehicles were converted (either by new purchase or repower) from diesel to propane-fueled engines.[42] One new propane engine reduced NO_x emissions in this equipment by an average of 0.3 tons per year, and a repower of one engine eliminated more than half a ton per year.

Unit Cost The incremental cost of a new, alternative-fuel terminal tractor ranges from $17,000 to $29,600.[43] Table 2-8 summarizes unit costs for the replacement of diesel engines with propane engines. Terminal tractors are currently available for compressed (CNG) and liquefied (LNG) natural gas, as well as for propane.[44] Although an electric hybrid straddle carrier costs roughly 10 percent more than a standard diesel model, it reduces fuel and other operating costs.[45] A rubber-tired gantry crane that is completely electric also costs roughly 10 percent more than comparable models.

Electric forklifts currently constitute one-quarter of the market for moderate-size forklifts.[46] They would be appropriate for smaller-capacity uses at terminals, where the charging infrastructure can be installed and there is adequate time to allow for recharging. The Carl Moyer Program in California has funded more than 200 electric forklifts at a cost of roughly $10,000 each.[47] California inventories

TABLE 2-7
Types of Alternative Cargo-Handling Vehicles and Equipment

Category	Usage	Engine Horse Power	Available Alternatives
Terminal Tractors	Shuttle containers around; the most prevalent type of equipment	150–250	Propane, LNG, CNG
Straddle Carriers	Transfer containers between stacks and trailers	Up to 500	Diesel-electric hybrid
Rubber Tired Gantry Cranes	Stacks containers	400–600	Electric
Forklifts	Lift various cargo	50–250	Electric, propane, CNG[a]

Sources: "Marine Terminal Design to Minimize Diesel Emissions" presentation given by Richard A. Woodman, P.E. at the Diesel Air Emissions Seminar on 24 October 2001. *The Port of New York and New Jersey Emissions Inventory for Container Terminal Cargo Handling Equipment, Automarine Terminal Vehicles and Associated Locomotives*, prepared by Starcrest Consulting Group, LLC, for the Port Authority of New York & New Jersey, June 2003.

a Sold by Yale, northamerica.yale.com/lift_trucks/pneumatictires/index.asp; and Clark Material Handling Company, www.clarkmhc.com

TABLE 2-8
Emissions Reduced from New Purchases and Repowers of Off-Road Engines with Propane

Project Type	Equipment Type	Engine HP	No. of Engines (Tons/yr)	Project NO_x Reduction	Project NO_x Reduction (Tons over 7-year Life)	Baseline Engine Cost ($)	Cost of Cleaner Engine ($)
New	Yard Hostler	195	5	1.5	18.3	N/A	N/A
New	Yard Spotting Tractor	195	2	0.6	8.3	$53,000	$60,000–$70,000
Repower	Yard Spotting Tractor	195	5	2.7	39.9	0	$20,000

Source: The Carl Moyer Program Status Report, 13 April 2001.

show that all forklifts greater than 175 horsepower are diesel; however, natural gas and propane models make up the majority of forklifts between 50 and 175 horsepower.[48]

The cost of a moderate-sized, full-service, natural gas fueling station ranges from \$500,000 to \$1,000,000.[49] The cost difference between an LNG and a CNG refueling infrastructure is not significant. A \$250,000 to \$500,000 additional investment will allow for CNG availability at an existing LNG fueling station (i.e., LNG/LCNG Station). In many cases, a fuel supplier will provide infrastructure equipment at no cost to the user in return for a substantial fuel-supply agreement and a guaranteed throughput of vehicles.[50,51] In contrast, refueling infrastructure for LPG (propane) is relatively inexpensive when compared with NG. In exchange for a long-term fuel contract of three to five years, fuel suppliers often absorb the cost of infrastructure, requiring the fleet operator or user to pay only the cost of necessary electrical upgrades ranging from \$1,000 to \$5,000.[52]

The Port of Barcelona reports driver satisfaction and a 30 percent drop in fuel use with its electric-hybrid equipment.

Cost-Effectiveness Alternative-fuel yard tractors have a cost-effectiveness of \$3,500 to \$6,600 per ton of NO_x reduced, making them a fairly cost-effective way to reduce NO_x emissions.[53] This figure is based on capital expenditures for the incremental cost of the alternative-fuel engines over their diesel counterparts. This does not, however, include the installation of a fueling station for alternative fuels. Grants, such as those from California's Carl Moyer Program, often cover at least three-quarters of the incremental costs of the alternative-fuel vehicle. The average cost-effectiveness for such alternative-fuel programs is estimated at \$4,000 per ton, not including infrastructure costs. According to the Carl Moyer Program, electric forklifts reduce an average of three-quarters of a ton of NO_x per year per forklift at a cost-effectiveness of roughly \$5,000 per ton.[54] We were unable to estimate cost-effectiveness of alternative-fuel forklifts and hybrid-electric straddle carriers.

EXAMPLES ▶ In 1999, a terminal operator at the Port of Los Angeles was awarded funds that facilitated the purchase of five LPG yard tractors through the Carl Moyer Program. Despite reduced efficiency and the need for more frequent fueling, the tractors have been able to do the work at the terminal.

Additionally, as a result of the lawsuit against the Port of Los Angeles (see *The Dirty Truth About U.S. Ports*), the China Shipping Terminal is expected to have all alternative-fuel yard tractors by the end of 2004.

The Port of Barcelona reports driver satisfaction and a 30 percent drop in fuel use with its hybrid straddle carrier demonstration project.[55] In the United States, the Port of Virginia is also testing several hybrid straddle carriers.[56]

A number of ports, including the Port of New York and New Jersey and the Port of Houston, report using propane or electric forklifts.

DISCUSSION ▶ Technological advancements, including lean burn, closed loop, and electronic fuel management, have improved the fuel economy and performance of alternative fuel engines. Although alternative fuel engines are still slightly less efficient than their diesel counterparts, they emit significantly less NO_x and PM.

Natural gas is a lighter-than-air gas, and therefore modifications to existing maintenance facilities are often necessary. The modifications usually consist of a methane-detection system, an improved ventilation system, and new lighting. Employee training and containment practices and procedures are also required.

Propane or liquefied petroleum gas (LPG), a byproduct of natural gas processing or petroleum refining, is a mixture of at least 90 percent propane, 2.5 percent butane and higher VOCs, and a balance of ethane and propylene. At room temperature, it is a gas, but it returns to liquid form when compressed. Unlike natural gas, LPG is heavier than air and therefore tends to accumulate toward the floor. LPG vehicles can be serviced at maintenance facilities that meet standards for use with gasoline or diesel vehicles, based on the number of air changes required per hour.

Retrofits and Repowers for Existing Equipment

Although the superior approach to cleaning up older equipment is to replace it with new, cleaner models, existing equipment with remaining useful life can be significantly cleaned up through retrofits and repowers. Under this approach, ports would fund an incentive program for marine terminal operators (MTOs) to repower and retrofit and to use cleaner fuel in cargo-handling equipment to reduce NO_x and diesel particulate emissions. MTOs that choose to repower their equipment would install newer, lower-emitting diesel engines to replace existing diesel engines. MTOs that retrofit would install add-on equipment to their existing engines or to their new repowered engines.

For repowering, the program should target existing "middle-aged" or recently purchased engines that are used extensively and that have relatively long remaining useful lives—generally speaking, engines manufactured between 1994 and 2003. Numerous new certified nonroad diesel engines in the appropriate size categories may be installed in place of older, dirtier engines. Target equipment would include

ALTERNATIVE FUEL SUCCESS STORY

The California grocery chain Stater Bros. has a fleet of 41 alternative-fuel vehicles, including six propane yard tractors. In 2001, Stater Bros. began operating the yard tractors, used primarily to arrange empty trailers after they are unloaded. Typical units log 5,150 hours of operation per year. The units are Ottawa Commando 30, powered by a 195-horsepower dedicated LPG engine that is available as an OEM product from Cummins Stater Bros., who report an overall fuel cost to savings on these units. Management has reported that the LPG units have performed satisfactorily under any legal load. Compared with new off-road diesel units, each of these yard spotters reduces NO_x emission by 2.75 tons per year. The average fuel cost per hour for diesel units was $2.38 per hour. During the same time period and under comparable operating conditions, the LPG units averaged $1.96 per hour. This is based on a fuel economy of 2.3 gph for LPG and 1.7 gph for the diesel units. The operational savings was realized from the different fuel cost of $1.42 for diesel and $0.92 for LPG.

Sources: Personal communication, Karen Sagen, Gladstein & Associates, December 2003.

regularly used yard hostlers, top-picks, side-picks, and straddle carriers. Several technologies have been shown to be cost-effective whether the engine repowers are installed on new or middle-aged equipment.

Diesel particulate filters (DPFs) and diesel oxidation catalysts (DOCs) are available in various configurations from a number of manufacturers and are used to reduce harmful particulate matter as well as CO and VOCs. Ports should favor retrofit equipment that has been "verified" or "certified" for effectiveness by the CARB or the U.S. EPA. However, because very few controls have been verified or certified specifically for use in off-road equipment, controls demonstrated in other applications or verified/certified for on-road use should also be considered, with consultation and approval from the manufacturer. Cleaner diesel fuels, necessary for many controls to function, are available in much of the country. For more information on control technologies, see Appendix B.

Pollutants Reduced Table 2-9 lists several common types of retrofit technologies, estimated pollutant reductions, fuel requirements, fuel penalty, and costs using the various technologies available.[57,58]

Unit Cost Estimated costs of various retrofit options are listed in Table 2-9. Estimates are based on 150–350 horsepower diesel engines. The cost of engine replacements,

TABLE 2-9
Pollutant Emissions Reductions Using Retrofit Technologies Available for Off-Road Sources

Technology	PERCENTAGE REDUCTIONS NO_x	PM	CO	VOC	Fuel Sulfur Tolerance	Fuel Penalty	Cost
Active Diesel Particulate Filter (DPF) & Lean NO_x Catalyst (LNC)[a]	25–35	50–90	50–90	50–90	Up to 15 ppm	3 to 7%	\$15,000–\$18,000
Electrically Regenerated DPF	—	80–95	[b]	[b]	Up to 15 ppm	1 to 2%	\$4,450–\$14,000, scaled to engine size
Flow-Through Filter (FTF)[c]	—	> 40	> 40	> 40	Up to 500 ppm	10%	\$700–\$7,000, most likely ~\$1,500–\$2,000
Diesel Oxidation Catalysts (DOC)	-	25[d]	30–90	40–90	Up to 500 ppm	0 to 2%	\$2,500–\$3,000
Exhaust Gas Recirculation (EGR)[e]	20–50	N/A[b]	N/A	N/A	Up to 500 ppm	0 to 5%	\$13,000–\$17,000
Lean NO_x Catalyst (LNC)[f]	10–20	N/A	N/A	N/A	Up to 250 ppm	4 to 7%	\$6,500–\$10,000

Sources: Cleaire; MECA; *CARB Diesel Risk Reduction Plan*, App. IX, October 2000; Clean Air Systems; Donaldson Corporation; and *EPA Technical Summary of Retrofit Technologies*, available at www.epa.gov/otaq/retrofit/retropotentialtech.htm.

Note: Emission reductions listed in this table may be less than those listed for on-road applications due to differing duty cycles. Where no information was available specific to off-road applications, emission reduction data from on-road applications were substituted.

a This retrofit, called "Longview" by trade name, has been verified by CARB for use on select on-road vehicles. The technology has been used by construction and other off-road vehicles; however, specific reductions for off-road applications are not yet available. Emission reductions are as reported by CLEAIREe, the manufacturer.

b Highly variable; may depend on fuel sulfur levels.

c Not yet commercially available; CARB verification is expected in 2004.

d DOCs have been verified for off-road use by CARB at this level. However, PM emissions reductions can be improved with very low sulfur levels. It should also be noted that when DOCs are used with regular EPA grade off-road diesel, which averages more than 3,000 ppm sulfur, PM emissions are likely to increase, according to MECA, *Exhaust Emission Controls Available to Reduce Emission from Nonroad Diesel Engines*, April 2003.

e PM emissions may increase slightly, especially with higher NO_x reductions; EGR should not be used without particulate controls.

f Not yet commercially available, unless bundled with a DPF or DOC. A DOC paired with an LNC currently costs \$10,000.

or repowers, ranges from $11,000 for the smaller yard hostler engines to $28,000 for larger equipment. Engine installation can be an additional $1,500 to $3,500 per unit.[59]

Cost-Effectiveness Cost-effectiveness for retrofitting or repowering existing cargo-handling equipment varies widely. The Port of Oakland reported that its program had achieved a $2,000 to $3,000 per ton cost for NO_x and PM reductions combined.[60]

Table 2-10 contains a summary of the ranges of cost-effectiveness control strategies for existing off-road equipment that is not yet ready to be retired and replaced. All of the NO_x control strategies, engine repowers, NO_x catalysts, and exhaust gas recirculation (EGR) are relatively competitive in terms of cost-effectiveness. The range of cost-effectiveness for PM controls is wider. Flow-through filters, when available, may offer one of the most affordable and effective solutions. In the meantime, active DPFs, DOCs, and repowers offer cost-effective PM reductions. Engine repowers and combination active DPFs with NO_x reduction catalysts offer cost-effective NO_x and PM reductions at the same time. Together, these two strategies offer an effective fleetwide solution, given that engine repowers are ideal on slightly older vehicles and active DPFs are compatible only with newer vehicles.

EXAMPLES ▶ In addition to the Port of Oakland, the Ports of Los Angeles and Long Beach have programs to retrofit or repower yard equipment. The Port of Long Beach expects by the end of summer 2004 to have installed more than 600 DOCs on its yard equipment at its seven major container terminals.[61] Similarly, the Port of Los Angeles has taken initial steps to clean up its approximately 800 pieces of mobile diesel yard equipment. The port has ordered and received 585 DOCs for installation on a variety of yard equipment, including yard tractors, side- and top-picks, and forklifts.[62]

The Port of Göteborg fitted all its terminal tractors and roughly one-third of its straddle carriers with DPFs, greatly reducing particulate emissions from cargo-handling operations and ensuring the use of very low-sulfur diesel, as needed for the DPFs.

TABLE 2-10
Cost-Effectiveness of Various Off-Road Control Strategies

Control Strategy	NO_x (Cost Per Ton)	PM (Cost Per Pound)
Engine Repower	$1,100–4,900	$8.40–17.40
Active DPF and NO_x Reduction Catalyst	$1,900–3,200	$6.40–9.30
Electrically Regenerated DPF	N/A	$1.80–7.20
Diesel Oxidation catalysts (DOC)	N/A	$2.40–4.60
Exhaust Gas Recirculation (EGR)	$1,100–3,800	N/A
Lean NO_x Catalyst	$1,400–4,500	N/A
Flow-Through Filter	N/A	$0.50–6.80

Assumptions: (1) Pollutant reduction percent and costs were taken from Table 2-9. (2) Baseline emission factors taken from 2003 Carl Moyer Guidelines, Table 3.1 and 3.4; emission factors for repower were assumed to be a 1988–1994 diesel engine with 176–250 HP replaced with a 2003 model; baseline EFs for all others were estimated as model years 1996–2002. (3) Project life was estimated as 8 years. (4) Operating hours of equipment was assumed to be 3,640 hours per year. (5) Load factor was assumed to be 50 percent.

DISCUSSION ▶ Many choices of exhaust controls for equipment are commercially available. The EPA and CARB have certified numerous replacement engines, and CARB has verified numerous control devices for various retrofit applications. Although most devices are verified for use only with on-road applications, many will also work well on cargo-handling equipment, depending on the fuel used and other factors such as engine temperature.

The Port of Oakland has acquired valuable field experience that can be applied at other ports to make an overall program more effective and cost-efficient. The Port of Oakland program is funded through a settlement that the port reached with the surrounding community over a recent expansion. Terminal operators can use the funds of this voluntary program to retrofit, repower, or purchase new and cleaner terminal equipment.

The Oakland experience indicates that the program must be well funded to achieve a high rate of voluntary participation from marine terminal operators. Sound administration is also a key to cost-effectiveness, and to the provision of adequate technical assistance. Some MTOs need technical assistance to sort out the claims of vendors competing for business. It may also be necessary to require retrofits or new purchases of older vehicles via new lease agreements or renegotiations.

Although Sweden's Port of Göteborg has successfully used "passive" diesel particulate filters on some cargo-handling equipment, not all equipment at the port regularly operates at exhaust temperatures high enough for DPFs to properly regenerate (i.e., burn off the particles they collect). Testing at the Port of Oakland indicates that most yard hostlers cannot use passive DPFs for this reason. It should be noted that "active" DPFs rely on different technology and are known to be compatible for use on yard equipment, regardless of operation.[63] Most DPFs, however, active or passive, do not work on the old two-stroke, mechanically controlled engines typical of model years before 1994. That is why an alternative-fuel approach for yard hostler applications in combination with a diesel oxidation catalyst system is a superior emissions reduction strategy.

Finally, converting existing diesel equipment to alternative-fuel use may now be possible with new technology. One company has developed a cost-effective method to convert older diesel trucks and buses to clean-burning natural gas. The process involves removing the cylinder head, removing diesel components, remachining the head and pistons for spark plug ignition, and adding a new system for fuel delivery, along with a close-coupled diesel oxidation catalyst in the exhaust system.[64,65]

Cleaner Diesel Fuels for Existing Equipment

The use of cleaner fuels is essential for certain pollution control devices to function properly. Cleaner fuels should be used throughout port facilities to prevent contamination of sensitive controls and for the additional, though modest, emission reductions from the fuels. Several options are available that are compatible with existing diesel engines in most nonroad vehicles and equipment, including low-sulfur diesel (15 ppm sulfur), diesel emulsions, biodiesel, Fischer-Tropsch diesel, and "E-diesel." Although low-sulfur diesel is the most widely available and the cheapest, the other four options offer higher emission reductions for certain pollutants if used alone without after-treatment equipment, as Table 2-11 indicates. Low-sulfur diesel is generally used in combination with a DPF or other pollution control device.

Pollutants Reduced and Costs Table 2-11 summarizes the various pollution reductions achieved by cleaner diesel fuels, as well as the fuel penalty and cost.

The CARB estimates that 20 percent of the diesel sold in California for on-road heavy-duty diesel vehicles has a sulfur content of 15 ppm or less. This low-sulfur diesel is currently manufactured in large quantities and is available throughout California, the Northeast, and most major metropolitan areas in the Northwest, Upper Midwest, and Texas.[66] The entire nation will be required to use low-sulfur diesel fuel for on-road vehicles by mid-2006.[67] In the meantime, where low-sulfur diesel is unavailable or terminal operators are unwilling to use it, on-road grade diesel can be substituted for nonroad grade diesel, which contains 10 times as much sulfur. The minimal cost difference, estimated at $0.01 to $0.02 per gallon, also allows the use of certain control technologies, such as diesel oxidation catalysts.[68]

Diesel emulsions are sold under several trade names, including Aquazole, Lubrizol, and Aquadyn, all of which have been verified by the CARB or the EPA.[69] Typically, the characteristics of diesel emulsions depend upon the type of diesel used as a base fuel, which may or may not be low sulfur depending on the specifications of the user. Low-sulfur diesel, however, must be specified as a base for diesel emulsions to ensure compatibility with emission controls and to maximize emission reductions. Emulsified diesel combined with DOCs is becoming a popular control strategy. Although it is on the high end of cost-effectiveness compared with other emission control strategies ($5,400 to $8,700 per ton of NO_x, and $15 to $25 per pound of PM), capital investments are modest, and the fuel can be used in any vehicle regardless of age.[70]

The Port of Houston has been running part of its cargo-handling equipment fleet on diesel emulsions for several years. The only problem reported has been that some equipment with extremely high power demands has been unable to generate sufficient

TABLE 2-11
Emission Reductions Achieved by Use of Various Cleaner Diesels[a]

Technologies	NO_x	PM	SO_x	CO	VOC	Fuel Penalty	Extra Cost (per gallon)
Low-sulfur diesel (LSD) fuel	3–11%	3–15%	>90%	6–10%	8–13%	~3%	$0.05
Diesel emulsions[b]	9–20%	16–64%				15–20%	$0.24–0.29[c]
Biodiesel (100%)	10–15% Increase	30–70%	>90%	50%	40–90%	4–10%	~ $1
Fischer-Tropsch diesel	4–12%	≤25%		18–36%	20–40%	2–4%	~$0.30
e-diesel	1–6%	20–40%		20–28%		~ None	$0.02–0.05

Sources: CARB, *Diesel Risk Reduction Plan*, Appendix IV, October 2000; CARB, *Verification of Fuels*, www.arb.ca.gov/fuels/diesel/diesel.htm; EPA Verified Technology list, www.epa.gov/otaq/retrofit/retroverifiedlist.htm; www.o2diesel.net/faqs.php.

a D Blume, Port of Houston, personal communication, August 2002.
b Emission reductions are in comparison to CARB diesel (<150ppm sulfur).
c CO and VOC emissions vary widely. Some tests show substantial increases, and others show great decreases.

power under certain circumstances. The port advises against its use for such equipment as "loaded container handlers," which lift and move containers and move them simultaneously. Other diesel emulsion users have reported similar problems with power loss in certain equipment, as well as a few other minor problems, including increased fuel-filter plugging, problems in cold weather, and the need to keep the fuel in constant use or regularly stirred to avoid separation.[71] However, diesel emulsions combined with a diesel oxidation catalyst offers extremely cost-effective and significant PM and NO_x reductions.

Biodiesel should be considered only in its pure form as opposed to a diesel blend. Although biodiesel is most commonly blended with 80 percent or more conventional diesel, the emission benefits of these blends are minimal and costs are not competitive. Pure biodiesel offers substantial PM and CO_2 reductions but increases NO_x (by as much as 15 percent). Unfortunately, most engine manufacturers do not warrant their products for use with pure biodiesel because it can cause problems in some engines.[72]

Biodiesel fuel is distributed in many parts of the United States, although prices vary widely, as does the feedstock used to produce it. Used oils and grease are preferable to farmed oils, where feedstock can be specified. The biodegradability and low toxicity of biodiesel makes it well suited for marine use.

Diesel emulsions combined with a diesel oxidation catalyst can offer cost-effective and significant PM and NO_x reductions.

Fischer-Tropsch diesel is usually made from coal but is sometimes made from natural gas, leading to the recent acronym GTL (gas to liquids) fuel. Much of the Fischer-Tropsch diesel in the United States is imported from Malaysia; however, new plants are likely to be built in the United States soon. In fact, several pilot plants are already operating, including one in Washington state. Costs are contingent on transport and feedstocks, and are not yet well-known.

E-diesel, also known as Oxydiesel, is a blend of conventional diesel and as much as 15 percent ethanol.[73] The ethanol, usually produced from corn, adds oxygen to the fuel, thus allowing it to burn slightly cleaner. Although this fuel recently received verification for use in California, emission reductions are modest, and safety concerns, such as flammability, remain to be addressed.[74]

A recent CARB study concluded that alternative diesel fuels provide relatively cost-effective reductions of PM, NO_x, and petroleum use. Fischer-Tropsch diesel and biodiesel offered some of the most cost-effective PM and petroleum use reductions, while NO_x reductions were demonstrated best by LNG and propane.[75,76]

EXAMPLES ▶ Northern Europe has led the way on use of cleaner diesel fuels and exhaust controls on marine terminal equipment.[77] The Port of Helsinki uses lower-sulfur diesel (30 ppm) in its own equipment and several marine vessels as an example to terminal operators. The port has proposed the use of cleaner fuels in cargo-handling equipment, heavy trucks, and marine vessels for its large new Vousaari Container Terminal Complex. The Port of Copenhagen Malmö in Denmark and Sweden also uses low-sulfur diesel (50 ppm) in cargo-handling equipment, which has also been fitted with diesel oxidation catalysts.

In the United States, the Port of Oakland has convinced most of its terminal operators to adopt low-sulfur diesel (15 ppm) for cargo-handling equipment. Addition-

AUTOMATED CARGO-HANDLING SYSTEMS:
The ports of Singapore and Rotterdam have led the way in improving efficiency of cargo handling and reducing associated pollution. The Port of Rotterdam, on the North Sea in the Netherlands, serves roughly 380 million European consumers. Rotterdam has several cutting-edge programs, including an effort to lessen environmental impacts through the use of inland barges instead of trucks and trains. However, the port's multitrailer system for moving containers in Europe's largest container terminal, the ECT, is truly noteworthy. Over the past two decades the multitrailer system has been refined to combine five yard tractors into one flexible trailer that can tow five containers at a time. Other major ports, such as Felixstowe in the U.K., the Port of Singapore, and the Port of Vancouver, have now studied and installed similar systems.

The Port of Singapore set a world standard for cargo-handling efficiency at its Pasir Panang Terminal in 2000, incorporating the latest in containerized cargo-handling technologies. The terminal is outfitted with nine-story tall, freestanding concrete structures supporting automated bridge cranes. These remotely operated cranes mark a major shift in container-handling yard systems because they are capable of very fast and flexible operations with a minimum number of operators. The terminal virtually eliminated diesel exhaust from cargo handling because the automated system is electrically powered. The cranes are controlled remotely from a crane operating center in the main terminal building, employing artificial intelligence to semiautomate the stacking andunstacking process.

Sources: Vernon E. Hall, V.E. Hall & Associates, personal communication, 1 July 2003; "Future Small Inland Vessels," by Richard Savenije, October 2000 edition of the *International Navigation Association's Bulletin* No. 105. PSA Corporation, Ltd. Appearing in the August 2000 issue of *Port Technology International* published by ICG Publishing Ltd., London, U.K.

ally, the Port of Houston has conducted the first demonstration of diesel emulsions on various cargo-handling equipment and one tour boat; indeed, the port now uses diesel emulsions in roughly 40 pieces of equipment. The Port of Long Beach is currently using emulsified diesel to fuel its yard equipment at two of its terminals. At one point, the Port of Los Angeles was running 600 pieces of yard equipment on emulsified diesel at four of its terminals. Due to water accumulation in storage systems caused by significant switching between and mixing of emulsified diesel and traditional diesel, two terminals have terminated their use of emulsified diesel. The Port of Los Angeles believes this issue has been resolved.[78]

ON-ROAD TRUCKS

Ports should pursue three major emissions reduction strategies, tailored to the age of the on-road trucks. First, pre-1984 trucks should be *replaced* with 1994 model year and newer trucks, which can then be equipped with after-treatment control devices. Second, model year 1994 and newer trucks should be *retrofitted* with a diesel particulate filter; older trucks (1984–1993) should be retrofitted with diesel oxidation catalysts. Third, all trucks should use cleaner fuels, such as diesel emulsions or low-sulfur diesel fuel, to further reduce emissions and ensure that after-treatment devices